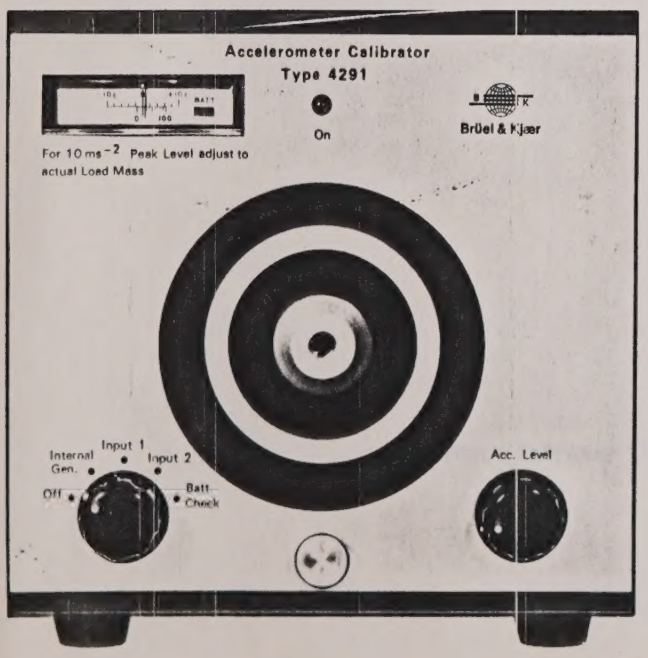
4291

Instruction Manual

Accelerometer Calibrator Type 4291



A fully portable vibration standard for field calibration of all kinds of vibration measuring systems and accelerometers at $10\,ms^{-2}$, $500\,rad\ s^{-1}$, with maximum ease of use. Provided with facilities for laboratory calibration techniques at other frequencies and levels. Internal battery or external 28 V DC operation.

Brüel & Kjær

033-0473

ACCELEROMETER CALIBRATOR
TYPE 4291

(from ser. no. 761 977)

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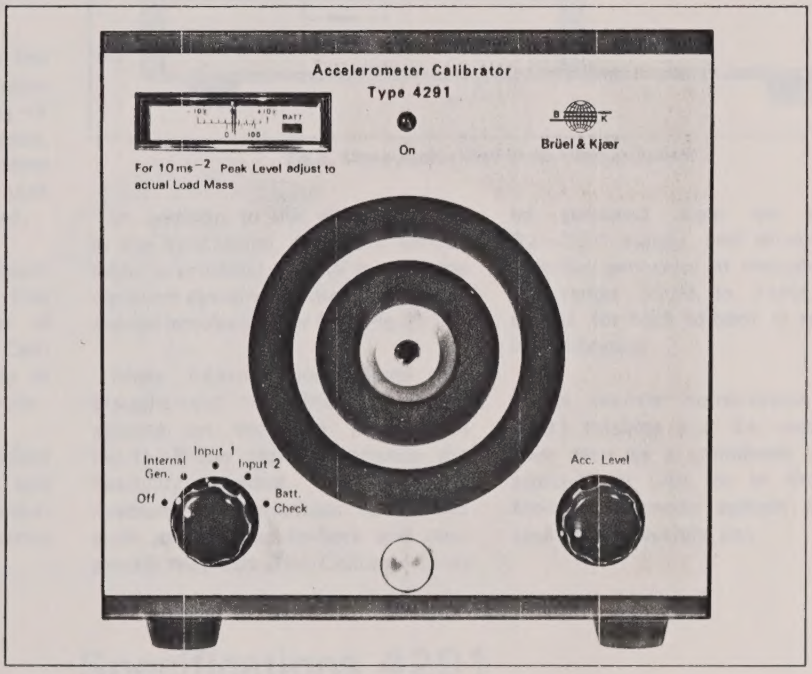
Accelerometer Calibrator

FEATURES:

- Internal batteries for portable, self-contained operation
- Stable, mechanically isolated vibration reference system
- Built-in velocity coil and suppressed-zero meter for precise, easy adjustment to reference vibration level
- ± 2% acceleration accuracy
- Reference level $10{,}0\ ms^{-2}$ acceleration, $20{,}0\ mms^{-1}$ velocity, $40{,}0\ \mu m$ displacement
- Internal generator for standard 79,6 Hz ($500\ rad\ s^{-1}$) operation
- Operates over 50 Hz to 2 kHz range with external generator

USES:

- Quick, simple field calibration of all kinds of vibration measuring systems
- Acceleration, velocity and displacement calibration
- Easy calibration of accelerometer charge and voltage sensitivity
- Back-to-back calibration of vibration transducers for increased accuracy
- Insert-voltage calibration of accelerometers
- Reciprocity calibration



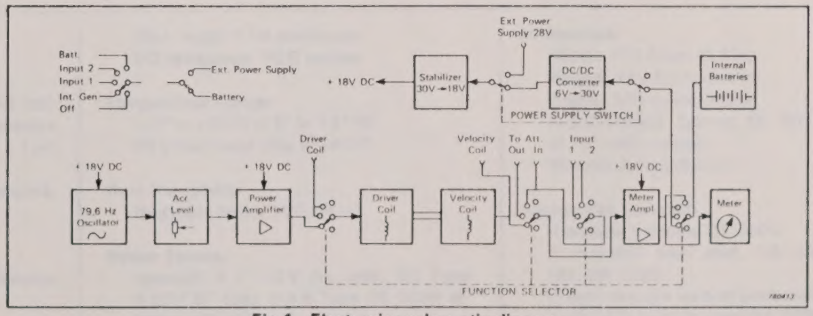


Fig.1. Electronics schematic diagram

The Accelerometer Calibrator Type 4291 provides a fully portable vibration reference source for field and laboratory calibration of vibration measuring and monitoring systems and individual vibration transducers, to a standard reference level.

It consists of a built-in, stable 79,6 Hz ($500\ rads^{-1}$) sinusoidal generator, a compact electromagnetic vibrator mechanically isolated from the case, and a velocity-monitoring coil feeding a built-in measuring amplifier and meter. The meter has a suppressed electrical zero to

enable the reference level to be set up quickly and precisely with better than 0,5% resolution.

The basic method of system calibration with the 4291 is extremely simple. The vibration transducer of the system to be calibrated is fixed to the vibration table, which is conveniently located in the centre of the front panel. The amplitude of the built-in generator is then adjusted by means of a 10-turn knob, also on the front panel, until the meter of the 4291 reads the mass of the transducer on its mass scale.

The table is then subjecting the transducer to a standard vibration acceleration level of 10,0 ms^{-2} peak at 500 $rad\,s^{-1}$ (80 Hz approx. — DIN 45666), which is equivalent to a velocity of 20,0 $mm\,s^{-1}$ peak and a displacement of 40 μm peak.

The vibration measuring system to be calibrated is adjusted so that its output indicates whichever of these quantities is appropriate. Calibration for acceleration, velocity or displacement is thus equally simple.

The 4291 is also very convenient for establishing the voltage and charge sensitivity of accelerometers, and identifying performance degradation due to damage.

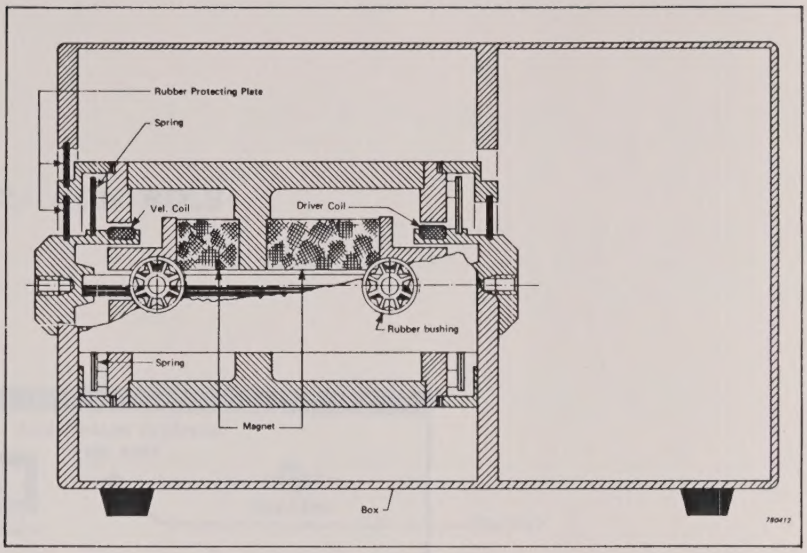


Fig.2. Cross-section view of the vibration system

In addition to the vibration table in the front panel, a second, similar table is provided, at the rear of the vibration system, for mounting a reference accelerometer (see Fig.2).

Most internal connections are brought out to miniature coaxial sockets on the rear panel (see Fig.1). These facilities provide the flexibility needed for laboratory methods of transducer calibration such as the back-to-back and reciprocity methods. The Calibrator may be powered from an external 22—28 V supply, and driven by an external generator at frequencies in the range 50 Hz to 2 kHz, if required, for back-to-back or reciprocity calibration.

The modular construction of the 4291 enables it to be used in its own case as a completely portable stand-alone unit, or in the B & K Modular Cassette system for 19" rack or field system use.

Specifications 4291

Internal Generator:
Frequency: 79,6 ±0,5 Hz (500 ±3 $rads^{-1}$)
Peak amplitude, ref. to calibrated output: 10,0 ± 0,2 ms^{-2} acceleration, 20,0 ± 0,5 $mm\,s^{-1}$ velocity, 40 ± 1 μm displacement (adjustable)
Distortion: less than 1% (at temperatures higher than 10°C)

Vibration System:
Mounting connections for accelerometers: 10—32 UNF tapped holes
Moving mass: 16 g approx.
Max. stroke: ± 1,5 mm displacement
Transverse amplitude: less than 10% of main axis amplitude at 79,6 Hz

Coils:
External frequency range: 50 Hz to 2 kHz
Max. input: 5 VA continuous
DC resistance: 70 Ω approx.

Temperature Range:
—5° to +55°C (23° to 131°F)
65 g load mass only to +40°C

Hum Sensitivity:
Negligible below 100 Am^{-1}

Power Source:
Internal: 4 × 1,5 V dry cells, IEC Type R 20 ("D" size), B & K Type QB 0004 alkaline cells (300 mA approx.)
Battery lifetime: 20 hours intermittent
External: 22—28 V DC (40 mA approx.)

Electrical connections:
Miniature coaxial sockets, accepting B & K Plug Type JP 0012

Mechanical:
Width: 139,5 mm (5,5 in)
Height: 132,6 mm (5,2 in)
Depth: 200,0 mm (7,9 in)
(B & K Module Cabinet KK 0024, 4/12 of 19" rack module)
Weight: 3,0 kg (6,6 lb)

Accessories Included:
4 alkaline batteries QB 0004
1 threaded steel stud, 10—32 UNF to M3, DB 1425
4 extra feet (for vertical positioning)
1 vibration formula chart BR 0008

Accessories Available:
Insert-voltage adaptor UA 0322

2. CONTROLS

2.1. FRONT PANEL

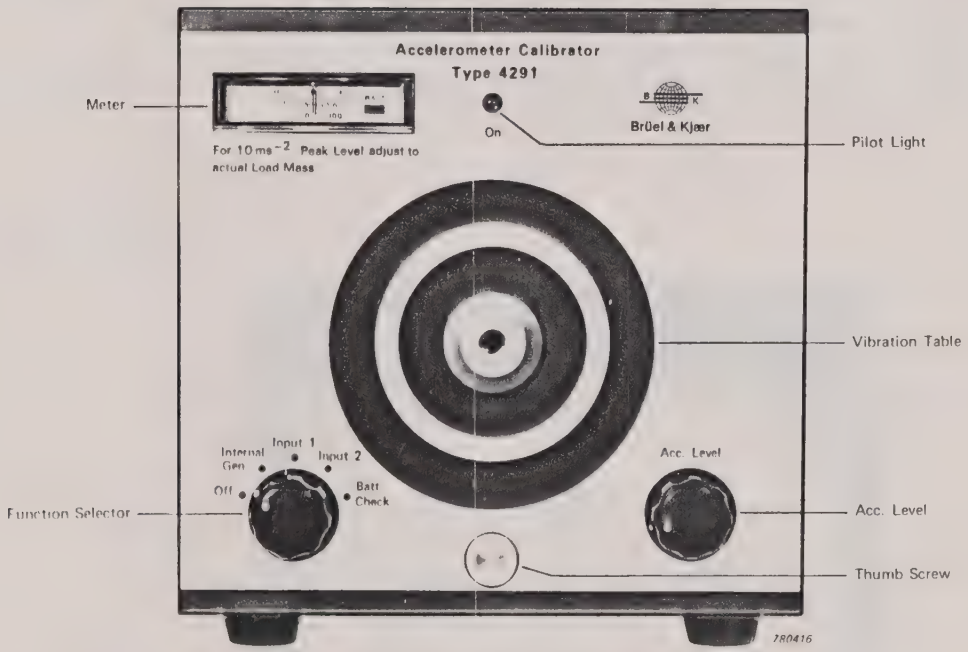


Fig.2.1. Front Panel of 4291

FUNCTION SELECTOR:

"Internal Gen." This is the position for basic calibration. In this position the vibration system is driven by the internal generator at 79,6 Hz (500 rad/s) and an amplitude which can be adjusted with the ACC. LEVEL knob. The peak acceleration at the accelerometer will be 10,0 ms^{-2} when the reading on the "0 ... 100" scale is equal to the accelerometer mass.

"Input 1" and "Input 2" positions are used only for back-to-back calibration. See chapter 3.

"Batt. Check." The pointer should indicate within the green "BATT." mark on the meter if the internal battery supply is being used. If it does not, replace the internal batteries. See section 2.4.

ACC. LEVEL:

A 10-turn potentiometer with which the vibration amplitude at the "Internal Gen." setting of the FUNCTION SELECTOR switch may be con-

tinuously adjusted from zero to about 2 to 3 times the normal calibration level.

METER: 2 scales:
(1) "—10% ... 0 ... + 10%". When the load mass on the vibration system is 20 g, "0" on this level scale indicates the normal calibration level of 10,0 ms^{-2} peak. "—10%" and "+ 10%" correspond to the indicated deviations from this level;
(2) "0 ... 100" is used for basic calibration of transducers whose mass differs from 20 g. When the mass indicated, in grams, is equal to the mass attached to the vibration system, the acceleration level will be 10,0 ms^{-2} peak.

PILOT LIGHT: Illuminated whenever the instrument has power connected and is switched on, except in "Batt. Check" setting of FUNCTION SELECTOR.

THUMB SCREW: Holds bottom plate in place or locks the instrument to the KK rack system. See also the Assembly Instruction Manual for the KK rack system.

2.2. REAR PANEL

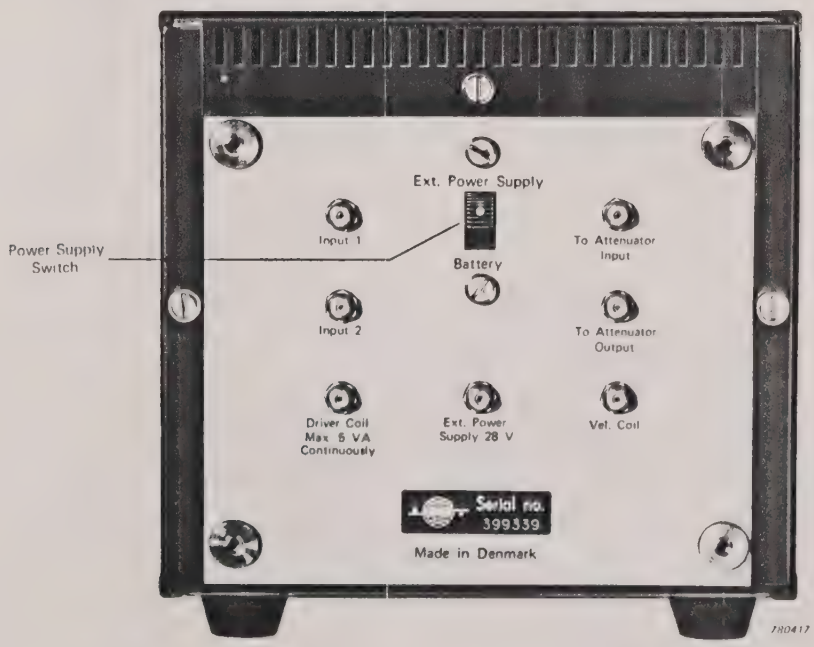


Fig. 2.2. Rear Panel of 4291

POWER SUPPLY SWITCH: For selection of internal battery supply or external 28 V power supply.

EXT. POWER SUPPLY 28 V: Mini-coaxial socket for powering the instrument from an external 22 to 28 V power supply (centre positive).

Note: the sockets below are used only in laboratory calibration methods. These are described in Chapter 4.

INPUT 1:	Connected, only at the "Input 1" setting of the FUNCTION SELECTOR switch, to TO ATTENUATOR INPUT socket.
INPUT 2:	Connected, only at the "Input 2" setting of the FUNCTION SELECTOR switch, to TO ATTENUATOR INPUT socket and the METER.
DRIVER COIL:	Connected, at the "Input 1" or "Input 2" settings of the FUNCTION switch, to the driver coil of the vibration system.
TO ATTENUATOR INPUT:	Connected to INPUT 1 or INPUT 2 sockets at the respective settings of the FUNCTION SELECTOR switch, and also to the METER in the latter case.
TO ATTENUATOR OUTPUT:	Connected to the METER when the FUNCTION SELECTOR switch is set to "Input 1".
VEL. COIL:	Connected to the velocity coil.

3. BASIC OPERATION

3.1. MOUNTING

The 4291 is designed to fit into the B & K Module System. Its metal cabinet may be used free-standing on its four rubber feet, or with its bottom panel removed may be mounted in the hardfoam plastic carrying-case KA 2000 or 19-inch rack-mounting frame KK 0014. These accept up to three modular instruments the same size as the 4291. For further information on the Module System, ask for the separate Data Sheets describing these products.

3.2. BATTERY INSTALLATION AND CHECKING

3.2.1. Dry cells

The 4291 is delivered with four 1,5 V long-life alkaline dry cells QB 0004 (IEC Type R 20). When fitted in the internal compartment of the instrument, these provide approximately 20 hours of semi-continuous operation before needing to be replaced.

3.2.2. Battery installation and replacement

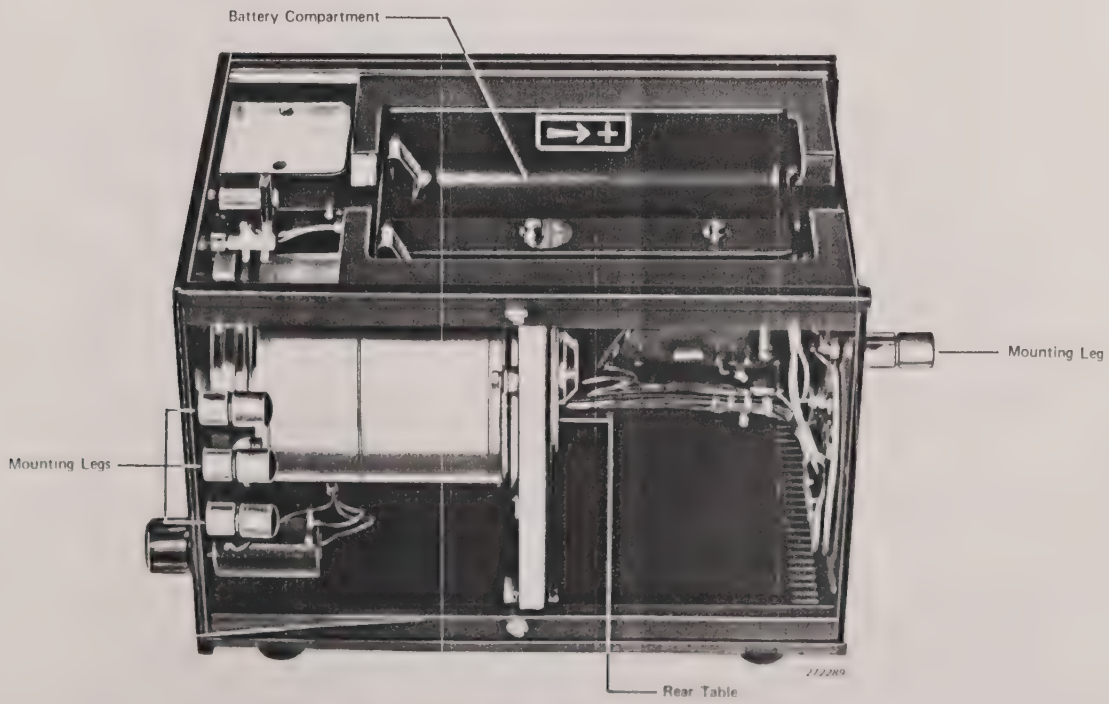


Fig. 3.1. Side view with top and side panel removed

Access to the battery compartment is made by removal of the top panel as shown in Fig.3.1. For internal battery operation the POWER SUPPLY SWITCH on the rear panel should be set to "Battery".

3.2.3. Battery check

To check the batteries, switch the FUNCTION SELECTOR to "Batt. Check". Discard the batteries if the pointer on the METER does not lie within the green "BATT." mark.

3.3. BASIC SYSTEM CALIBRATION AT 10,0 ms^{-2} PEAK

The basic method of vibration system calibration with the 4291 is very straightforward and easy. Sufficient accuracy for the majority of applications can be obtained with no additional equipment besides the 4291 itself, nor are any calculations required. Vibration measuring and monitoring systems displaying acceleration, velocity or displacement may be calibrated with equal facility because the 4291 vibration table excites the system's transducer sinusoidally at a known frequency (500 rad/s^{-1}) and amplitude (10,0 ms^{-2} acceleration, 20,0 mms^{-1} velocity, 40 μm displacement, all quantities peak sinewave).

The basic method of system calibration uses the internal generator and the internal METER. An example of a typical vibration measuring system under calibration is shown in Fig.3.2, using a B & K Measuring Amplifier to measure the signal from the Accelerometer Preamplifier.

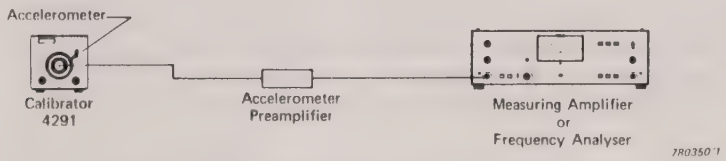


Fig.3.2. Typical calibration arrangement

The procedure is as follows:

1. Ascertain the mass of the Accelerometer from its calibration chart.

2. Mount the Accelerometer (finger-tight is sufficient) to the table by means of a 10—32 UNF stud. For accelerometers having a 3 mm stud, use the 3 mm-to-10-32 UNF adaptor (DB 1425). For accelerometers not having a stud or tapped hole, use the cementing stud (DB 0756) and wax or cement.

3. If the internal battery supply of the 4291 is to be used, switch the FUNCTION SELECTOR to "Batt. Check". If the METER deflection falls outside the green "BATT." mark, replace the batteries.

4. Switch the FUNCTION SELECTOR to "Internal Gen." The Calibrator will now vibrate the accelerometer at 79,6 Hz (i.e. 500 radians/second).

5. Adjust the ACC. LEVEL control until the METER pointer coincides with the load mass on the "0 ... 100 gram" scale. The load mass is the total mass attached to the vibration system, usually the accelerometer to be calibrated and the mounting-stud (the latter is generally negligible). The accelerometer is now subjected to a sinusoidal acceleration of 10,0 ms^{-2} peak ± 2%.

6. To calibrate for velocity or displacement, the appropriate "Vel." or "Disp." integration network, if any, should be selected on the Accelerometer Preamplifier.

7. Adjust the gain of either the Accelerometer Preamplifier or the Measuring Amplifier so that the latter reads the reference level of 10,0 ms^{-2} ± 2% peak or one of the equivalent values in the list below, as appropriate.

When steps 1 to 7 above have been completed, the sinusoidal vibration at the accelerometer is as follows:

Peak acceleration	= 10,0 ms^{-2}
Peak-to-peak acceleration	= 20,0 ms^{-2}
RMS acceleration	= 7,07 ms^{-2}
Peak velocity	=20,0 mms^{-1}
Peak-to-peak velocity	= 40,0 mms^{-1}
RMS velocity	=14,1 mm^{-1}
Peak displacement	= 40,0 μm
Peak-to-peak displacement	= 80,0 μm
RMS displacement	= 28,3 μm

The accuracy of the basic calibration method depends on the velocity coil, meter amplifier and METER, which are adjusted accurately by the manufacturer, at the frequency of the internal generator. The METER deflection is proportional to the **relative** velocity of the coil and its associated magnet, and this is influenced by the mass on the vibration table. The METER is preset at the factory to deflect to a value on its mass scale equal to the mass mounted on the table when the absolute velocity is 20 mm s^{-1} peak at the generator frequency of 79,6 Hz (500 rad s^{-1}). At other frequencies this correspondence between relative velocity and absolute velocity cannot be assumed because the magnet system itself is free to move on its suspension. Therefore if it is required to perform calibration at some other frequency, using an external generator, one of the laboratory methods of calibration described in Chapter 4 should be used.

3.4. BASIC ACCELEROMETER CALIBRATION

The 4291 provides a basic method to ascertain the voltage or charge sensitivity of an accelerometer to ± 2% with maximum simplicity. The result can be compared with the sensitivity value provided on the accelerometer calibration chart for checking whether the accelerometer has been damaged.

An arrangement such as the one illustrated in Fig.3.2 is required. The procedure is as follows:

1. Perform steps 1 to 5 of section 3.3, BASIC SYSTEM CALIBRATION AT 10,0 ms^{-2} PEAK.

2. Calibrate the Measuring Amplifier by means of its internal reference voltage. Refer to the Measuring Amplifier Manual.

3. Set the Measuring Amplifier to read voltage. If it has the facility for displaying Peak Volts, switch it to this mode.

4. Note the reading. If it is in RMS Volts, convert it to Peak Volts using the following relationship for a sinewave:

   Peak Volts = 1,414 × RMS Volts

5. The sensitivity of the Accelerometer and preamplifier is given by the equation:

$$\text{Sensitivity} = \frac{\text{Peak Volts}}{10{,}0} \text{ V per ms}^{-2}$$

6. To calculate the sensitivity of the Accelerometer, divide the sensitivity obtained in step 5 by the gain setting of the Accelerometer Preamplifier. If this is a voltage preamplifier, the gain setting will be in volts per volt, i.e. a number, and the Accelerometer voltage sensitivity calculated will be dependent on the capacitance of the cable actually used. If a charge preamplifier is used, its gain setting will be in volts per picoCoulomb (VpC^{-1}), and the Accelerometer charge sensitivity calculated will normally be independent of the cable.

For more information, refer to the Instruction Manual for the Accelerometer Preamplifier, and the Piezoelectric Accelerometer and Vibration Preamplifier Handbook available on request from B & K.

4. LABORATORY CALIBRATION METHODS

4.1. BACK-TO-BACK CALIBRATION

4.1.1. Description

Back-to-Back calibration is a comparison calibration method where the unknown accelerometer and a reference accelerometer are mounted on a carefully controlled vibration generator. The sensitivity of the unknown accelerometer is obtained by comparing the outputs of the two accelerometers.

This is a useful technique for obtaining higher accuracy of calibration than permitted by the internal circuit of the 4291. Where a standard accelerometer or accelerometer of known sensitivity is available, the accuracy of the method is limited only by the resolution of the Measuring Amplifier used. The method should also be used where the calibration is to be performed at a frequency other than 79,6 Hz.

To facilitate simple and accurate Back-to-Back calibration, the 4291 has a rear mounting table, directly coupled to the front table, on which the second accelerometer may be mounted. Access to this table is obtained by removing the right-side plate (instrument viewed from front) (see Fig.3.1).

4.1.2. Back-to-Back Calibration using an External Voltmeter

Fig.4.1 shows a suitable arrangement for Back-to-Back calibration using an External Voltmeter. The Sine Generator is not needed if calibration is to be at 79,6 Hz only.

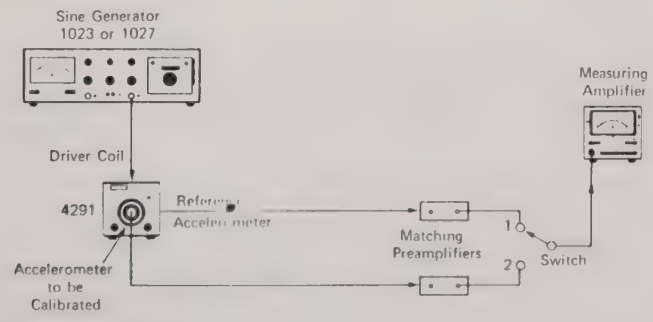


Fig.4.1. Back-to-Back calibration using an external Voltmeter

If the Type 8305 Standard Accelerometer is used as the reference accelerometer, and the unknown accelerometer is mounted directly onto the 8305, then the full frequency range (50—2000 Hz) of the 4291 may be utilized.

If the unknown and reference accelerometers are mounted one on each table of the 4291, then the Frequency Range should be limited to 50 to 300 Hz to avoid any possible errors due to the relative motion of the tables.

Note also that transverse motion is below 10% between 80 Hz and 120 Hz.

The procedure is as follows:

1. Remove the right-hand side panel as in Fig.3.1.

2. Secure the Reference Accelerometer to the rear table (Fig.3.1).

3. Secure the Accelerometer to be calibrated to the front table.

4. Connect up the instruments as shown in Fig.4.1.

5. Set the switch to position 1.

6. If the internal generator is to be used, set the FUNCTION SELECTOR switch to "Internal Gen." and adjust ACC. LEVEL, to obtain a convenient, arbitrary level at the Measuring Amplifier, in the region of 10 ms^{-2} .

7. If calibration is required at a frequency or frequencies other than 79,6 Hz, set the FUNCTION SELECTOR to "Input 1" or "Input 2" and the frequency of the Sine Generator to the value required. Adjust the output level of the Generator to obtain a convenient, arbitrary level at the Measuring Amplifier, in the region of 10 ms^{-2} .

8. Note the level, V_1 , at the Measuring Amplifier.

9. Switch the Switch to position 2.

10. Note the new level, V_2 , at the Measuring Amplifier. The sensitivity of the unknown accelerometer is given by:

$$S_u = S_R \frac{V_2}{V_1}$$

where S_u is the sensitivity of the unknown accelerometer, referred to the output of the Preamplifier, and S_R is the sensitivity of the Reference Accelerometer, referred to the output of the Preamplifier.

The value of S_R will usually be known to an accuracy of ± 1%, so the accuracy with which S_u may be determined depends on the ratio V_2/V_1. Note that the absolute values of V_1 and V_2 are not required, so the Measuring Amplifier need not be chosen for its absolute accuracy. Scale resolution and scale linearity are the limiting parameters. It is important that V_1 and V_2 be measured on the same range of the Measuring Amplifier. The accuracy may be improved by setting the Switch to whichever position gives the greater deflection on the Measuring Amplifier Meter, and adjusting the output of the Sine Generator to give Full Scale Deflection in this setting.

For increased stability of the acceleration level, connect the compressor input of the Sine Generator to the output of the Accelerometer Preamplifier in the Reference Accelerometer channel. Refer to the Sine Generator Manual for information about adjustment of the compressor.

4.1.3. Back-to-Back Calibration using Conditioning Preamplifiers

Back-to-Back calibration may be performed most easily if two Conditioning Preamplifiers are available. The arrangement is shown in Fig.4.2.

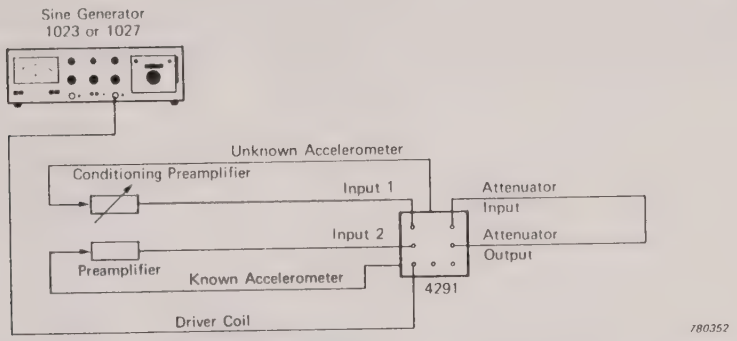


Fig.4.2. Back-to-Back calibration using Conditioning Preamplifiers

The calibration procedure consists of adjusting Conditioning Preamplifier 1, used with the unknown accelerometer, to obtain the same overall sensitivity as the known accelerometer plus Conditioning Preamplifier 2.

The outputs of the Preamplifiers are measured on the internal METER of the 4291 via the meter amplifier, which requires an input of typically 130 mV RMS for zero deflection of the METER. It is necessary to ensure that the combination of Conditioning Preamplifier 2 and the known accelerometer are capable of producing this voltage at a prevailing acceleration level of about 10 ms^{-2}.

The procedure is as follows:

1. Set the Sine Generator to the frequency required and the output amplitude to about 2 V RMS.

2. Dial in to Conditioning Preamplifier 2 the sensitivity of the known accelerometer.

3. Switch the FUNCTION SELECTOR on the 4291 to "Input 2" and adjust Conditioning Preamplifier 2 "Volt/Unit Out", for coarse changes, and the Sine Generator ouput amplitude for fine changes to obtain zero deflection on the METER of the 4291.

4. Set the Conditioning Preamplifier 1 to the same "Volt/Unit Out" setting as Conditioning Preamplifier 2.

5. Switch to "Input 1" and adjust the accelerometer sensitivity setting of Conditioning Preamplifier 1 to restore zero deflection to the 4291 METER.

6. The sensitivity of the unknown accelerometer may be read directly off the setting of Conditioning Preamplifier 1.

4.1.4. Back-to-Back Calibration using a Calibrated Voltage Divider

The internal METER is designed to be read with good resolution — better than 1% — and this is achieved by displacing the electrical zero from the scale. Thus if the ratio of

two levels is to be determined from readings taken off the METER, the ratio must lie between 0,82 and 1,22 (corresponding to the scale limits —10% and + 10%).

Except where nominally similar accelerometers are to be calibrated, the sensitivity ratio is likely to fall outside this range, and some other calibrated instrument is required. A suitable instrument is a calibrated Voltage Divider (Attenuator). Using this enables the internal METER of the 4291 to be used in place of a Measuring Amplifier. It is however, essential to provide an external Sine Generator. The arrangement is shown in Fig.4.3.

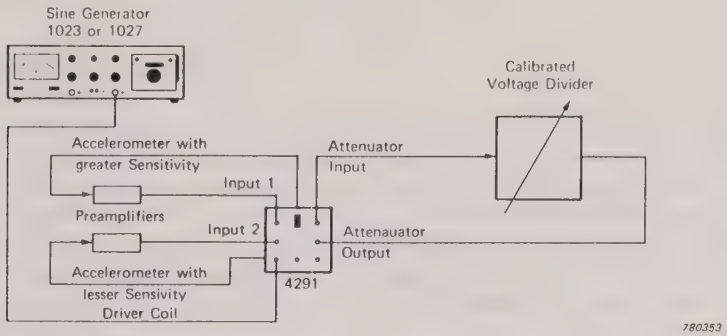


Fig.4.3. Back-to Back calibration using a calibrated Voltage Divider

The choice of Preamplifier may be influenced by the requirement that at the vibration level used the voltage at Input 2 should be equal to the voltage corresponding to zero METER deflection, approximately 130 mV RMS.

1. With the instruments connected as shown, switch the FUNCTION SELECTOR to "Input 2".

2. Adjust the output of the Sine Generator to obtain zero deflection on the 4291 METER.

3. Switch the FUNCTION SELECTOR to "Input 1".

4. Adjust the Voltage Divider to restore a zero deflection to the METER of the 4291.

5. Switch back and forth between "Input 1" and "Input 2" once or twice and compensate for any drift which may have occurred.

6. Note the transfer ratio K of the Voltage Divider.

7. The sensitivities S_1 , S_2 of the Accelerometers are related by the equation:

$$S_2 = KS_1$$

The subscripts correspond to the respective input numbers.

The relevant internal connections of the 4291 are indicated in Fig.4.4.

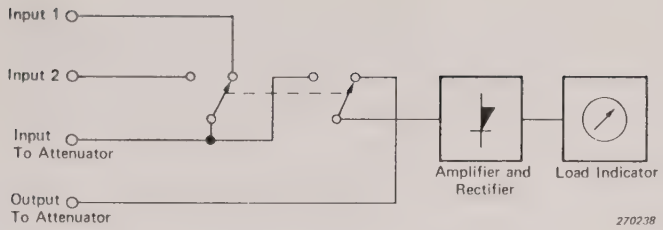


Fig.4.4. Internal connections of 4291

4.2. INSERT VOLTAGE CALIBRATION

Using the Adaptor UA 0322 shown in Fig.4.5, calibration of the open circuit voltage sensitivity of an unknown accelerometer may be determined by applying the insert voltage method. The advantage of the method is that the accelerometer output need not be open circuit but may be terminated by a finite impedance such as the input impedance of a preamplifier. Furthermore, accelerometers that have been calibrated by the method may be rechecked without removing them from arrangements in which they are used for measurements. This is particularly advantageous in multichannel vibration measurement systems.

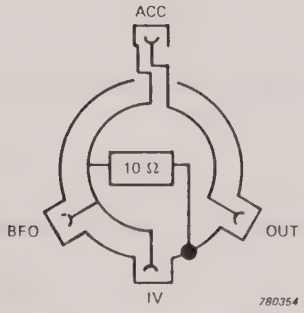


Fig.4.5. Insert Voltage Adaptor UA 0322

The principle of insert voltage calibration can be explained with reference to Fig.4.6. The accelerometer to be calibrated is first vibrated at a known acceleration level a_o causing it to produce the open circuit output voltage V_{ao} which when loaded by the preamplifier input produces the voltage V_1 at the output of the preamplifier as in Fig.4.6(a). The vibration source is then removed and voltage V_{ao} substituted by an insert voltage V_c. This is applied in series with the accelerometer via a resistance r and produces the voltage V_2 at the preamplifier output as in Fig.4.6(b). Provided that r is small compared with the preamplifier input impedance (with UA 0322 r = 10Ω) and that V_c is adjusted so that $V_2 = V_1$ then the insert voltage V_c will correspond exactly to the open circuit voltage V_{ao} of the accelerometer. Consequently by measuring V_c the open circuit voltage sensitivity S_{vo} of the accelerometer may be determined using the relation:

$$S_{vo} = \frac{V_c}{a_c} \quad \text{V per ms}^{-2}$$

Any convenient Sine Generator, such as Types 1023 or 1027, may be used to generate V_c at the BFO input. A suitable Measuring Amplifier or Electronic Voltmeter will be required to measure V_1, V_2 and V_c at I.V.

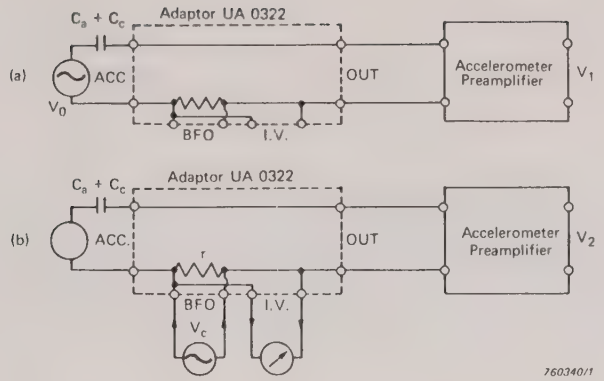


Fig.4.6. Principle of insert voltage calibration of accelerometers

The procedure is as follows:

1. Follow steps (1) to (5) of section 3.3 above.

2. With the arrangement in Fig.4.6(a), measure V_1 . The Sine Generator may if desired be connected before this is done provided its output is set to zero.

3. Switch the FUNCTION SELECTOR of the 4291 to "Off".

4. Connect the Sine Generator as shown in Fig.4.6(b), if this has not been done previously.

5. Set its frequency to 79,6 Hz.

6. Increase the Sine Generator output voltage while observing V_2, until $V_2 = V_1$.

7. Measure the insert voltage V_c at I.V.

8. Calculate the accelerometer sensitivity S_{vo} from the equation

$$S_{vo} = \frac{V_c}{10,0} \text{ V per m/s}^2$$

Note: The open circuit voltage sensitivity obtained in this manner is referred to the "Acc." input socket of the Adaptor, i.e. to the accelerometer plus the cable between the accelerometer and the Adaptor. Normally the open circuit sensitivity of the accelerometer alone is not required since the same cable arrangement will be used in subsequent calibrations with the Adaptor. However, if the open circuit voltage sensitivity S_a of the accelerometer without cable is required then this may be determined from:

$$S_a = S_{vo} \frac{C_{ac} - C_{cl} + C_{cs} + C_i}{C_{ac} - C_{cl}}$$

where C_{ac} is the capacitance of the accelerometer, including the 1,2 m cable supplied with it
C_{cs} is the capacitance of the short cable between the accelerometer and the Adaptor (approx. 9 pF with the cable supplied with the Adaptor)
C_{cl} is the capacitance of the 1,2 m cable supplied with the accelerometer
C_i is the input capacitance of the Adaptor (approx. 3 pF)

4.3. RECIPROCITY CALIBRATION

4.3.1. Description

Reciprocity Calibration is a technique of absolute measurement of accelerometer sensitivity in terms of mass, frequency and electrical resistance. These quantities can easily be measured to ± 0,1% or better using a chemical balance, a counter-timer and a universal bridge respectively. The method is therefore suitable for laboratory calibration of accelerometers in situations where better accuracy is required than the ± 2% attainable with the 4291 on its own, using readily obtainable instruments.

Reciprocity calibration utilizes the reciprocal correspondence between mechanical and electrical variables at the ports of an electrodynamic transducer which is reversible, linear and passive. The transducer used in the method described here is the velocity coil of the 4291, since it has all three characteristics. A total of three transducers is required including the Accelerometer to be calibrated, but only one of them needs to be reversible and passive.

Two arrangements of the equipment are required, to measure R and Y, which are defined below. R is obtained with the 4291 Driver Coil exciting the vibration system; Y is obtained with the 4291 Velocity Coil exciting the vibration system. Each quantity is obtained with and without a known Insertion Mass M attached to one of the vibration tables, whence R and Y assume the respective suffices M and O.

The sensitivity S_{acc} of the combination of the accelerometer and preamplifier used with it is given, in SI units (i.e. V per ms^{-2}) by the following expression:

$$S_{acc} = \sqrt{\frac{M}{\left(\frac{Y_M}{R_O} - \frac{Y_O}{R_M}\right)\omega}}$$

where Y = velocity coil current/Preamplifier output voltage
R = Preamplifier output voltage/unloaded velocity coil voltage
ω = angular frequency (rad s^{-1})
= $2\pi f$

4.3.2. Equipment Requirements

The arrangements of equipment for measuring the four quantities R_O, R_M, Y_O, Y_M are shown in Figs.4.7 and 4.8. There are many possible variations on the configurations shown, however. The particular advantage of the 2010 Heterodyne Analyser is that it provides both a sinewave source and a selective measuring amplifier, permitting measurement at a low level without sacrificing the 60 dB signal-to-noise ratio necessary for 0,1% accuracy of measurement.

However, if a B & K Reciprocity Calibration Apparatus Type 4143 is available, it may be used in place of the Switch, the Voltage Divider and the measuring amplifier section of the 2010. In this case, a separate Sine Generator such as Type 1023 must be provided.

The 4291 should be operated with the FUNCTION SELECTOR in either "Input 1" or "Input 2" position, it does not matter which. Its internal circuitry is not used, so if the

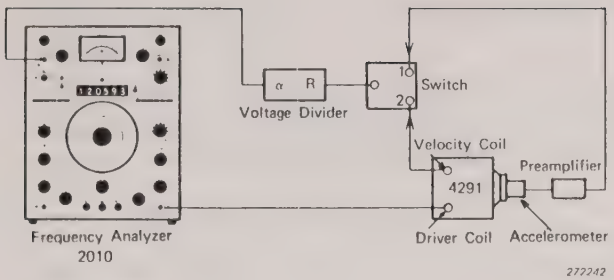


Fig.4.7. Connection of equipment for the measurement of R_O, R_M

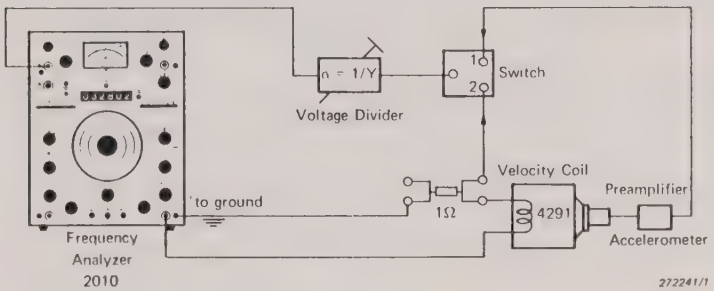


Fig.4.8. Connection of equipment for the measurement of Y_O, Y_M

4291 is fitted with batteries, preserve them by switching the POWER SUPPLY SWITCH to "Ext. Power Supply". In the equipment arrangement for measuring Y_O, Y_M, the chassis and signal common of the 4291 are not earthed directly because of the one-ohm resistor in the earth (screen) side of the velocity coil socket. The vibration table, however, may be earthed through the case of the Accelerometer since there is no internal connection between the vibration system metalwork of the 4291 and its chassis.

The one-ohm resistor should be of the four-terminal type to eliminate errors due to contact resistance. If it differs from 1,0 Ω by more than the intended experimental error, allowance should be made for this in the calculation, which assumes that the voltage across it is numerically equal to the current in it.

The Insertion Mass should be weighed accurately, and designed so that it may be inserted between the Accelerometer and the 4291 vibration table. It should be carefully machined to have a good surface finish and parallel mounting surfaces. Its weight should be 1 to 4 times the combined weight of the accelerometer and the 4291 moving mass.

The 4291 will give best results at frequencies between 100 and 1,0 kHz; at higher frequencies, the first axial resonance begins to influence measurement.

4.3.3. Measurement Procedure

The procedure for obtaining R_O, R_M, is as follows.

1. Connect up the equipment as in Fig.4.7.

2. Set the Voltage Divider to unity.

3. Find out which Switch position gives the lesser deflection on the measuring amplifier meter, and select it.

4. Adjust the level of the signal to obtain a convenient meter deflection near to full scale deflection on the appropriate range, at as low an acceleration level as possible consistent with obtaining a 60 dB signal-to-noise ratio. Note the deflection.

5. Switch to the other Switch position.

6. Adjust the Voltage Divider to restore the same deflection to the measuring amplifier meter.

7. R_O or $1/R_O$, depending on which Switch setting gave the lesser deflection, is read off the Voltage Divider setting. The setting gives R_O directly for the lesser deflection at position 1 of the Switch, and vice versa.

8. Attach the Insertion Mass in the correct position (see above) and repeat steps 1 to 7 to obtain R_M.

The procedure for obtaining Y_O, Y_M, is as follows.

1. Connect up the equipment as in Fig.4.8.

2. Repeat steps 2 to 6 above.

3. Y_O or $1/Y_O$, depending on which switch setting gave the lesser deflection, is read off the Voltage Divider setting. The setting gives Y_O directly for the lesser deflection at position 2 of the Switch, and vice versa.

4. Attach the Insertion Mass in the correct position and obtain Y_M by repeating the procedure as for Y_O. Determine S_{acc} by inserting the values obtained for Y_M, R_O, Y_O, R_M and M in the expression given above. ω is calculated by reading the frequency off the 2010 digital Frequency Display and multiplying by 2π.

5. OPERATING CHARACTERISTICS

5.1. ELECTRONIC CIRCUIT

The electronics schematic diagram is given in Fig.1.

In order to use the internal power supply, the battery voltage must be stepped up. Since battery voltage is dependent upon such things as discharge rate and temperature, and is liable to fluctuate, a stabilized 25 kHz converter, utilizing five transistors and a Zener diode, transforms it into the necessary 18 volt source. Variations in battery voltage can be fully compensated for with this arrangement, provided the boundary values are not exceeded. To some small extent, the voltage is temperature dependent, but in the given operating temperature range, the variation is insignificant. The condition of the batteries can be checked on the monitoring meter.

The battery compartment is sealed off from the amplifier section, thereby ensuring that no corrosive vapours or fluids can penetrate to the electronic or mechanical parts.

The internal generator employs a Wien-bridge transistor oscillator. This consists of a pair of RC circuits and a two-stage inverting amplifier. À negative-temperature-coefficient (NTC) resistor is used in a negative feedback loop to stabilize the amplitude of oscillation. This method ensures a low-distortion waveform. The RC circuits fix the frequency of oscillation at 79,6 ± 0,5 Hz (500,0 ± 3,0 rad s^{-1}).

The power amplifier increases the signal amplitude from the oscillator and provides an impedance match between oscillator and driver coil. The signal level is controllable by the potentiometer operated by the ACC. LEVEL knob.

The meter amplifier circuit consists of an integrated circuit amplifier, a rectifier, and a balancing circuit. By using a balancing circuit, it is possible to get a null point on the meter which corresponds to 100% output from the amplifier. The needle returns to this point when power is off. Fig.5.1 shows a typical relation of meter deflection to amplifier input.

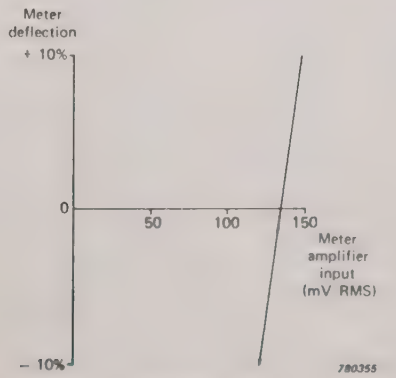


Fig.5.1. Typical relation of METER deflection to meter amplifier input

5.2. VIBRATION SYSTEM

In Fig.2 is shown a cross-section of the vibrating system. The vibration exciter consists of the mechanically coupled vibrating tables, each with a coil wound about it, electrically isolated from the magnetic assembly and case. The complete moving system weighs about 16 grams. This system is set in a permanent magnetic field which, due to differences in size and shape of the magnets, is stronger at one end than the other. The driver coil end is magnetized as much as possible, while the magnet in the velocity coil end is artificially aged to make its field as stable as possible.

The moving coils have a DC resistance of approximately 70 Ω.

A virtually frictionless suspension within the magnet housing is provided by leaf springs which allow a maximum amplitude of ± 1,5 mm. The magnetic housing itself is suspended by rubber bushings within the instrument casing. Flexible rubber discs protect the internal workings from dust and moisture.

Figs.5.2 and 5.3 show the typical frequency curves of acceleration of the front and back tables. The number 1 indicates the suspension resonance, 2 and 3 indicate the first and second major resonances.

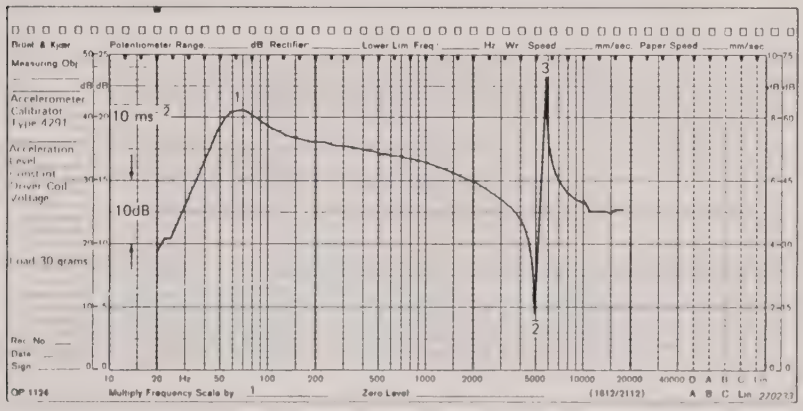


Fig.5.2. Acceleration vs. frequency for constant drive voltage - front table

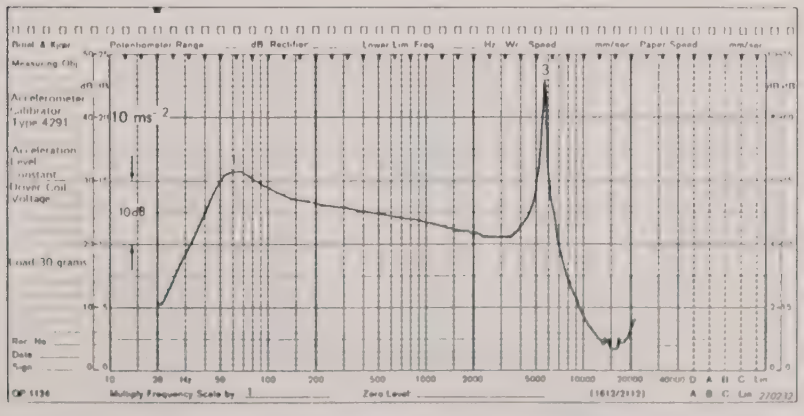


Fig.5.3. Acceleration vs. frequency for constant drive voltage - rear table

5.3. CHARACTERISTICS

The influence of temperature on the accuracy of the 4291 is shown in Fig.5.4.

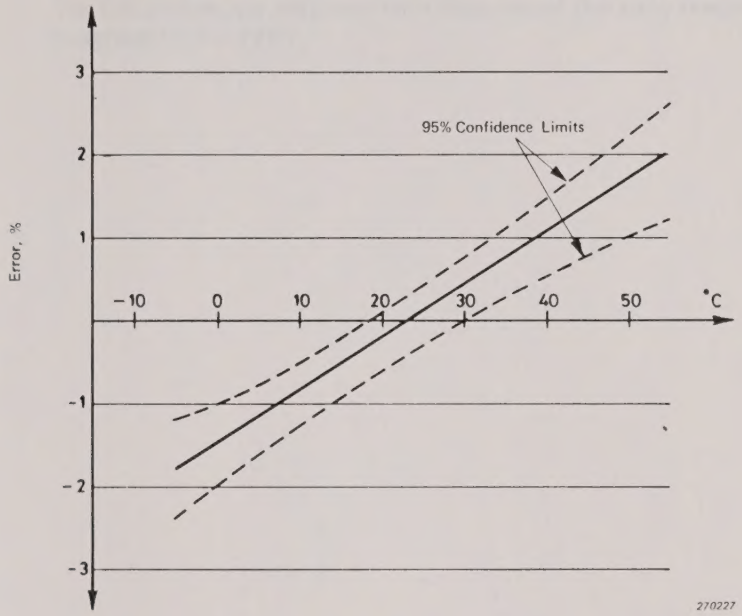


Fig.5.4. Effect of temperature upon accuracy

The vibration system has a basically axial movement with horizontal and vertical symmetry. Some transverse motion is possible, but this is frequency dependent and a proper choice of frequencies helps limit the problem. The best choice lies between 80 Hz and 120 Hz, where the transverse motion is less than 10% of the axial.

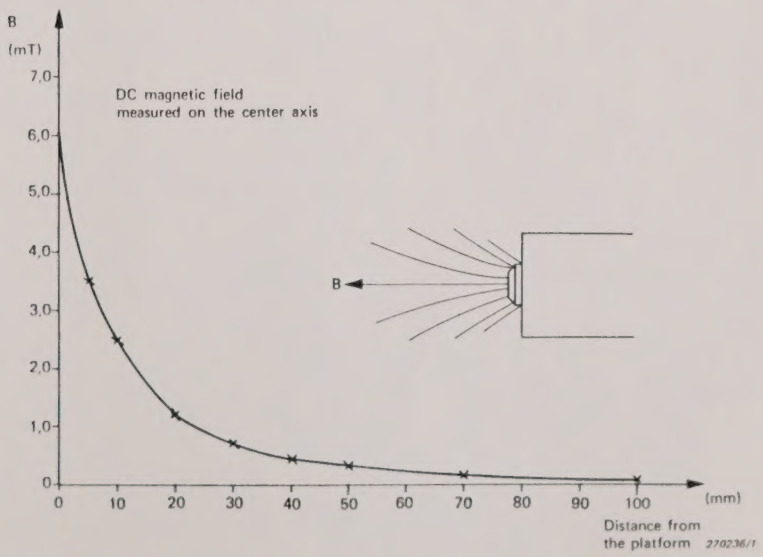


Fig.5.5. Variation of the strength of the magnetic field around the 4291 with distance

In any case, the influence of transverse motion on calibration accuracy is small, since the accelerometer itself does not have much transverse sensitivity. For example, if the transverse motion is 7% and the transverse sensitivity of the accelerometer is 3%, the error is only about 0,2%.

Fig.5.5 shows the variation with distance of the stray magnetic field from the permanent magnets in the 4291.

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